PROJECT PROMETHEUS, *The Nuclear Systems Program*

Revolutionizing Solar System Exploration

Presentation to
Structure and Evolution of the Universe
&
Origins
Subcommittees

October 24, 2003

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"…the navigation of interplanetary space depends for its solution on the problem of atomic disintegration…"

Robert H. Goddard, 1907

PROJECT PROMETHEUS

History

- Project Prometheus initiated in response to identified limitations of current paradigm for Solar System exploration
  - **Solar power limits power budgets and can be of limited use in outer planetary system**
  - **Chemical propulsion can limit maneuverability and destinations**
- Initial mission studies, detailed technical analysis, and industry surveys completed in early 2003
- Nuclear Systems Initiative included in President's FY03 Budget and renamed Project Prometheus in President's FY04 Budget
  - **Congress jump started a first Project Prometheus mission with an unexpected FY03 allocation for the Jupiter Icy Moons Orbiter (JIMO) mission**
  - **House approved President's FY 04 budget; Senate approved minus $20 million (which said was provided in FY03 for JIMO)**
- Support from Administration shows commitment that nuclear electric propulsion and power can be an essential addition to future NASA missions and the JIMO mission has been identified to potentially take advantage of the scientific opportunities enabled by Project Prometheus technologies.

PROJECT PROMETHEUS

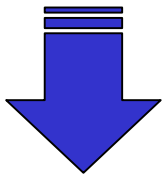
Supporting NASA's Mission

The NASA Mission:

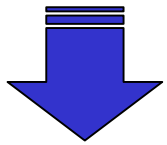
"To understand and protect our home planet, ***to explore the universe and search for life, to inspire the next generation of explorers*** . . . as only NASA can."

Space Science Enterprise Themes

- Astronomical Search for Origins
- Structure and Evolution of the Universe



- Solar System Exploration
- Mars Exploration
- Sun Earth Connection



Project Prometheus supports the NASA Mission and the Space Science Enterprise Themes by providing mission planners with:

Reliable, long-lived, rugged power sources, from milli- to multi-kilowatt, using radioisotope and fission reactor power systems that would maintain our current exploration capabilities while enabling new classes of missions not possible with current power and propulsion systems.

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Match the Power System to the Destination

Relative Size of Planets

Power and Propulsion Systems

Solar Electric Best Suited to Inner Solar System

– Also limited reach to large outer planetary bodies with aerocapture (Jupiter, Saturn, Uranus, Neptune only)

Radioisotope Electric for New Frontiers Class Outer Solar System Missions

- 500-1,000 W
- <50 kg payload
- 5 MT EELV ~ high energy earth departure

Nuclear Fission Electric for Large Flagship Missions to Outer Planets

- 10s – 100s kW
- >500 kg Payloads
- 20MT EELV ~ low energy earth departure

RTG for Surface Lander and Fission Reactors for Planetary Bases

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Key Technology Components

Energy Generation
- Fission reactor
  (10s-100s of kWs)

Conversion to Electricity
- Static: Thermoelectrics, Thermophotovoltaic
- Dynamic: Stirling, Rankine, Brayton

Energy Generation
- Radioisotope
  (milli to kilowatts)

Electricity Utilization
- Electric Propulsion
- Scientific Instruments
- Communications

Space Science Missions

Jupiter Icy Moons Orbiter (JIMO) mission

Mars, New Frontiers, TBD

Future Prometheus-Enabled Missions

Ensuring safety is our paramount objective and all program activities will be conducted in a manner to achieve this objective.

PROJECT PROMETHEUS

Organizational Principles

- Organize for safety and mission success
- Establish clear lines of responsibility and authority
- Enable focus on mission systems engineering and optimization
- Enable responsiveness to science mission customers
- Utilize the capabilities of industry, academia, and the US Government via a competitive process to achieve innovative solutions and optimal cost and performance
  - Utilize capabilities of US Government to manage and implement this program
    - DOE regulatory responsibility and authority (Atomic Energy Act) for the development and operation of systems using special nuclear material (e.g., reactors)
    - DOE authority to indemnify developers of reactors and related activities
    - NASA has unique and extensive experience in the launch and operation of deep space spacecraft
  - Utilize capabilities of NASA, main players will be
    - GRC, JPL, KSC, and MSFC – with expertise in planning, design, management, development, and operation of deep space missions, launch of spacecraft including those with nuclear materials, large spacecraft structures and systems, engines, propulsion systems, SE&I for complex programs, electric thrusters, power conversion, power management, etc.
    - HQ responsible for science selection, mission selection, proposal selection, advanced planning, and program control
  - Utilize the capabilities of instrument developers and scientists throughout the world
    - Universities
    - Industries
    - NASA centers such as GSFC, JPL, and LaRC
    - DOE laboratories

Project Prometheus

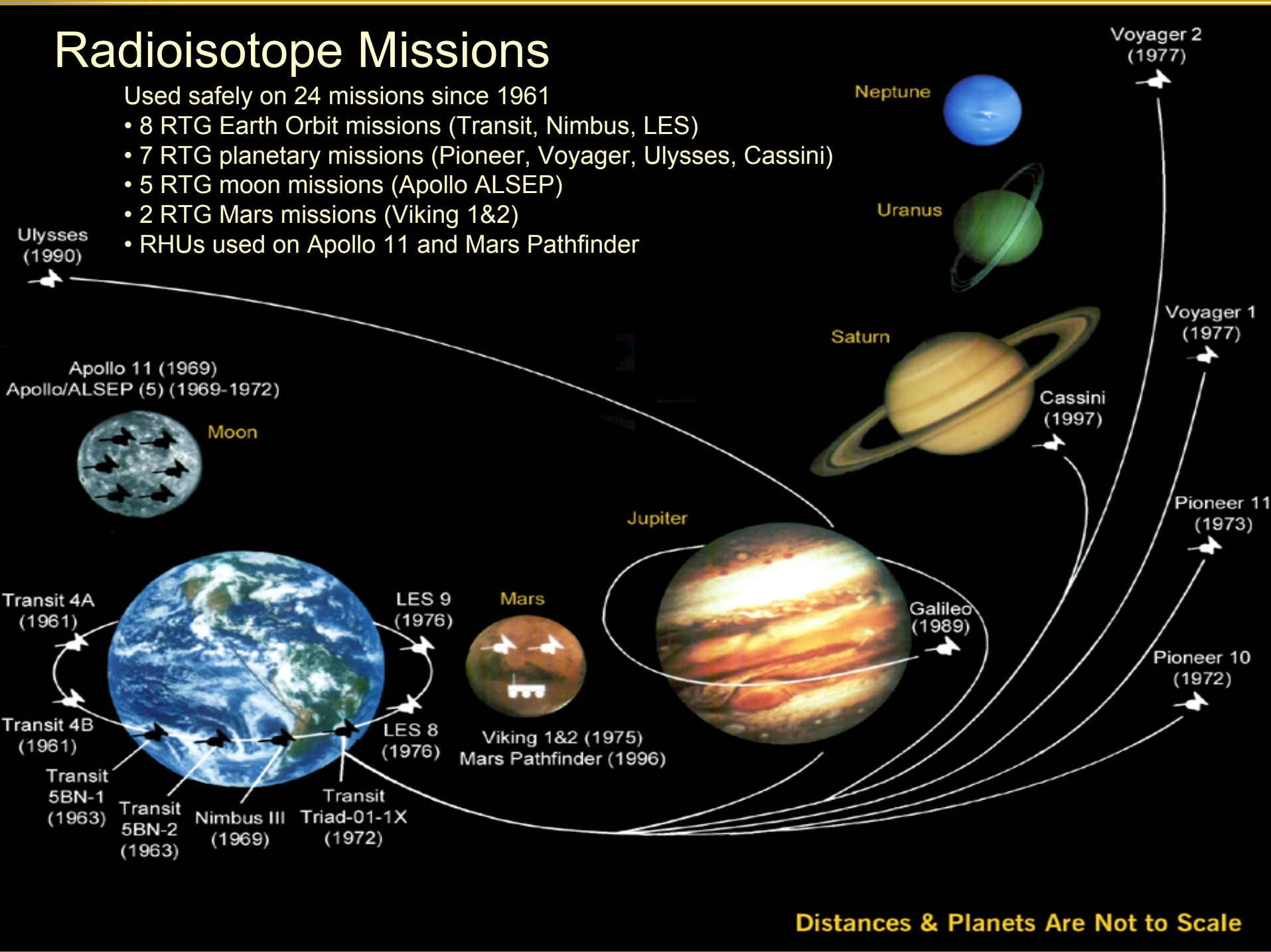
Designing for Safety

- NASA has over 30 years' experience in the successful management of radioisotope power systems (RPS)
- Working with DOE, we would apply that safety experience to the design, manufacture, and flight of a fission reactor
  - The reactor would be specifically designed to prevent accidental criticality while still in the Earth environment
  - We are engaging NASA and DOE expertise in continuous safety management and risk assessment
- NASA Will Fully Comply with Environmental and Nuclear Safety Launch Approval Processes Applicable to the Use of Nuclear Power Systems in Outer Space
  - National Environmental Policy Act (NEPA)
    - Purpose: Ensure NASA considers the potential environmental impacts of a proposed mission (or program) and reasonable alternatives
    - Entails: Environmental Assessment or Environmental Impact Statement (EIS), as appropriate
      - EIS provides opportunity for public engagement
  - Presidential Directive/National Security Council Memorandum #25 (PD/NSC-25) (as amended)
    - Purpose: Ensure informed decision-making at the Presidential level before launching a mission with radioisotope power systems or nuclear reactors.
    - Entails: NASA/DOE safety analyses, interagency safety evaluation, and nuclear safety launch approval by Director of OSTP or the President.

Radioisotope Missions

Used safely on 24 missions since 1961

- 8 RTG Earth Orbit missions (Transit, Nimbus, LES)
- 7 RTG planetary missions (Pioneer, Voyager, Ulysses, Cassini)
- 5 RTG moon missions (Apollo ALSEP)
- 2 RTG Mars missions (Viking 1&2)
- RHUs used on Apollo 11 and Mars Pathfinder



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Radioisotope Power Systems Development

Objective: Support NASA's mission "…To explore the universe and search for life," by providing NASA mission planners and the space science community with reliable, long-lived, rugged power sources, from milli- to multi-hundred watt, using radioisotope power systems.

- Only 1 un-fueled radioisotope power system in current inventory (2006 Pluto mission)
- 30 safely flown by NASA on 17 missions (2 more missions used RHUs only)

Program Components:

- Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) Development (DOE)
- Stirling Radioisotope Generator (SRG) Development (DOE)
- Advanced Power Conversion Technology Research (NASA)
- Advanced Systems Development (NASA/DOE)
- Purchase Plutonium-238 from Russia for Civil Use (DOE)

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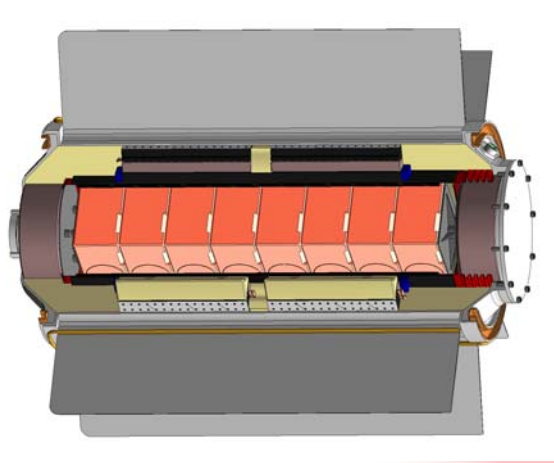
Radioisotope Power Systems Development

Multi-Mission RTG

Objective: By the end of this decade provide space science mission planners with small thermoelectric-based nuclear power sources capable of operating in space, on Mars, and on other solar system bodies using state-of-practice technology.

- Provides approximately 120 Watts of electrical power (~90 W(e) at 14 years) for scientific instruments and spacecraft operations.
- Minimal use of new technology – based on same power conversion technologies used on RTGs for Viking, Galilleo and Cassini programs but with half the power output and fuel requirements.
- Provides continuous all-day/all-night operation at any location and latitude.



MMRTG (design concept shown above) is low risk and based on technologies proven on previous applications, such as the Cassini mission.

Accomplishments and Future Plans:

- *Competitively awarded contract FY03 (DOE to Boeing-Rocketdyne and Teledyne Energy Systems)*
- Complete Engineering model FY05; Complete Qualification unit FY06; First unit available for flight FY08

Flight Candidates: Candidate for Mars Science Laboratory (CY09 launch); candidate for NASA New Frontiers Program missions (FY09 launch).

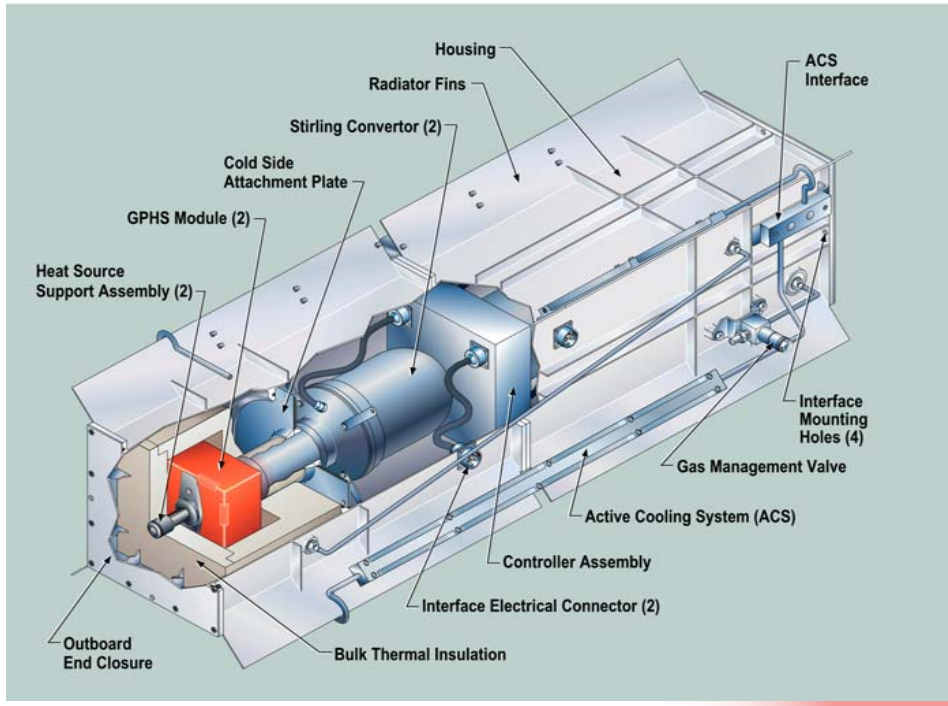
PROJECT PROMETHEUS

Radioisotope Power Systems Development

Stirling Radioisotope Generator (SRG) Development

Objective: By the end of this decade develop higher efficiency, Stirling cycle-based power units capable of operating in space, on Mars, and on other planetary bodies

- Provides approximately 120 Watts of electrical power for scientific instruments and spacecraft operations (same as MMRTG)
- Employs highly efficient Stirling dynamic energy conversion process which reduces Plutonium requirements substantially (up to ¾ less fuel) over current static conversion technologies
- Dynamic energy conversion well-proven on Earth and in flight with small cryocoolers



Stirling Radioisotope Generator (SRG) under development by Lockheed-Martin, Stirling Technologies and NASA Glenn

Accomplishments and Future Plans:

- *Competitively awarded contract FY02 (DOE to Lockheed-Martin)*
- Complete Engineering model FY04; Complete Qualification unit FY06; First unit available for flight FY08

Flight Candidates: Candidate for Mars Science Laboratory (CY09 launch); candidate for NASA New Frontiers Program missions (FY09 launch).

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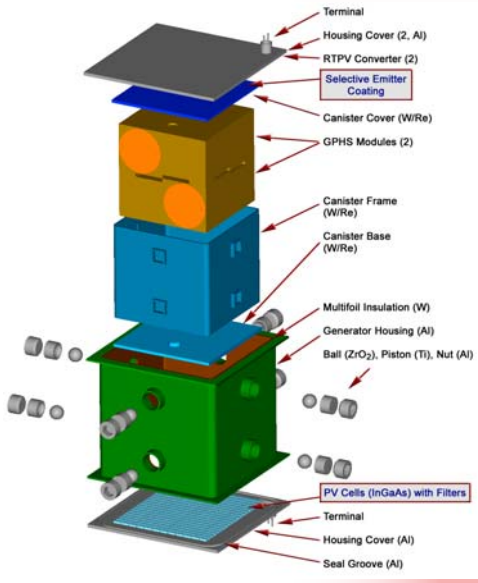
Radioisotope Power Systems Development

Advanced Power Conversion Research and Technology

Radioisotope Power Conversion Technology (RPCT) NRA – *GRC*

- 10 competitively awarded NRA contracts aimed at advancing power conversion technology for future RPS
- Selections covered thermoelectric, thermophotovoltaic (TPV), Stirling and Brayton power conversion technologies
- Objectives/Requirements:
  - Research (TRL ≤ 3) and development-focused (TRL ≤ 5) for milliwatt (~40 mW) and nominal (~100 W) systems (scalable to 1-10 W)
  - Improve efficiency, specific power and reliability over current state-of-practice
- Recent Accomplishments:
  - Awarded contracts and initiated negotiations with 10 project teams – signed and initiated x contracts (7 others expected by Sept 2003)



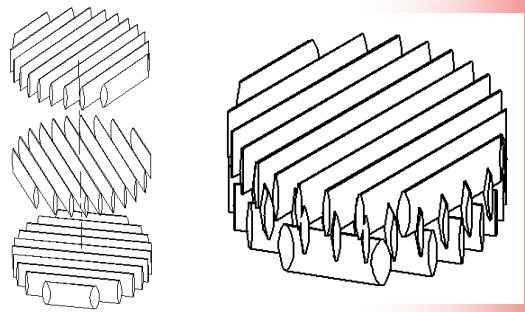
RPCT Project: TPV-based radioisotope generator (Creare, Inc.)

Advanced Stirling Research – *GRC*

- Direct-funded research on technologies for 2nd Generation SRG
- Focus on potential use of higher temperature materials, mass reduction, and improvement in controller reliability/operation
- Recent Accomplishments
  - Identified and evaluated candidate materials
  - Developed simulation of new controller operation

Segmented Thermoelectric Research – *JPL*

- Direct-funded research on higher efficiency thermoelectric technology
- Recent Accomplishments
  - Demonstrated 12.5% efficiency with single unicouple
  - Initiated buildup for extended duration tests of complete unicouples



RPCT Project: Applying micromachining methods to Stirling regenerator design (Cleveland State University)

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Radioisotope Power Systems Development

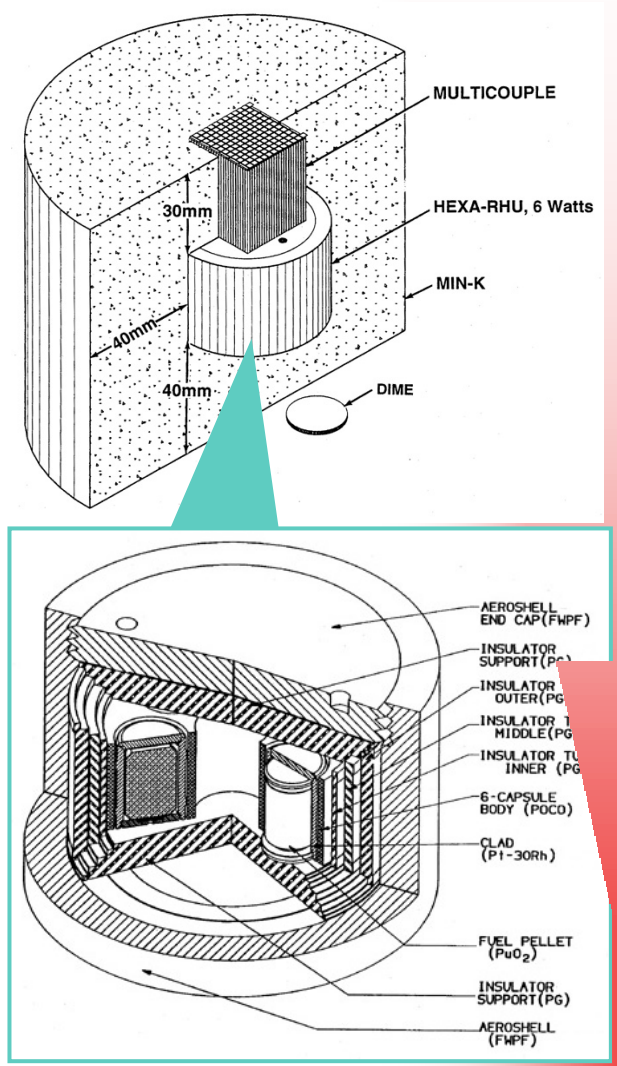
Advanced Systems Development

Objective: Develop advanced high-efficiency, high-specific power RPS systems that could greatly expand the capabilities and options available for future small-scale science missions

- 100 Watt-scale systems: Follow-on to current MMRTG and SRG developments (e.g., 2nd generation MMRTG/SRG)
- Milliwatt (~0.010 W) to Watt-scale systems: Small electric power supplies for Mars network science, remote sensing stations and very small spacecraft
- Factor of 2 to 5 improvements in power conversion beyond SOA in converter reliability, lifetimes, power levels, and overall efficiency

Accomplishments and Future Plans:

- *Completed preliminary concept definition study for single RHU and GPHS thermal sources*
- Initiate study for mid-range power concepts based on multiple RHU and fractional GPHS thermal sources
- Initiate development of small RPS – target application on Scout 11 mission (≥FY06)



Small 0.3-We RPS concept based on 6-RHU thermal sources (Fairchild 1994)

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Radioisotope Power Systems Development

Fuel Production

Objective: Ensure adequate supplies of plutonium fuel for future radioisotope power system-powered space exploration missions.

- Purchasing Plutonium-238 from Russia for Civil Use (DOE)
  - Fuel fabrication and testing (DOE)
- DOE investigating options for U.S. domestic production of Pu-238
- Current inventory and planned purchases will fuel three MMRTG and three SRG units (engineering, qualification and flight units)

Radioisotope Heater Unit: Iridium encapsulated fuel (silver), protective graphite and impact shells (grey) – 151 grams PuO_2 @ 62.5 watts (t) / 4 per GPHS / 16 GPHS per RTG / 8 GPHS per MMRTG / 2 GPHS per SRG

Accomplishments and Future Plans:

- Received 1 kg from Russia FY03 undergoing evaluation at LANL.
- Initiated acquisition of 5 more kg (scheduled for 2004) under new contract (allows purchase of 15 kg over next 5 years with an option for additional 15 kg)
- Issue RPS power/Pu-238 requirements forecast for OSS review

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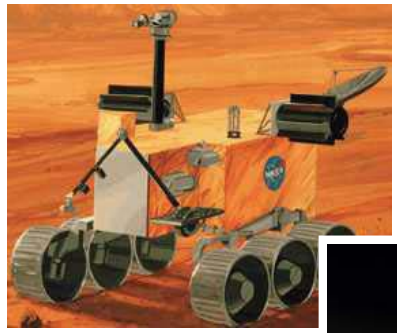
Potential RPS-Powered Missions

Mars Exploration Missions

Mars Science Laboratory

- Preliminary concept assessment (Pre-Phase A)
- In-situ evaluation of past or present habitable environments using a sophisticated mobile science laboratory
- Launch planned for 2009
- *Candidate for new ~100W-scale RPS (MMRTG or SRG)*

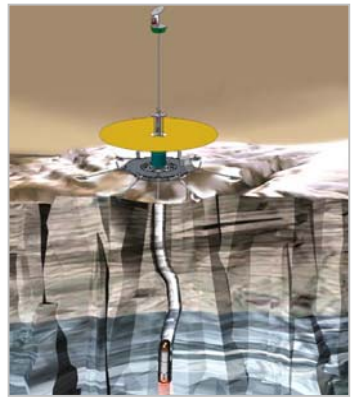


Example Future Mission Concepts

Mars Long-Lived Lander Network

Mars Scout Missions

Mars Sample Return



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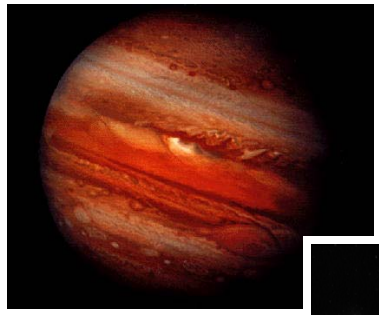
Potential RPS-Powered Missions

Near-term Interplanetary and Solar Missions

New Horizons Mission

- First mission in New Frontiers program
- Single-pass flyby mission of Pluto-Charon system followed by possible targeting of one or more Kuiper Belt objects
- Launch planned for 2006-2007 timeframe
- *Uses last remaining GPHS-RTG*

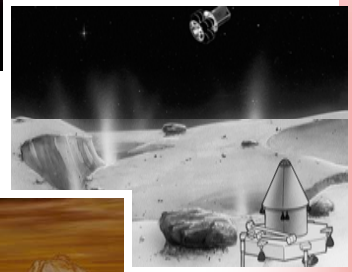


Example Future Mission Concepts

New Frontiers Missions

(Announcement of Opportuniity (AO) released)

- *South Pole/Aitken Basin Sample Return*
- *Jupiter Polar Orbiter with Probes*
- *Venus In-situ Explorer*
- *Comet Surface Sample Return*



Sun-Earth Connection Missions

- *Solar Probe*

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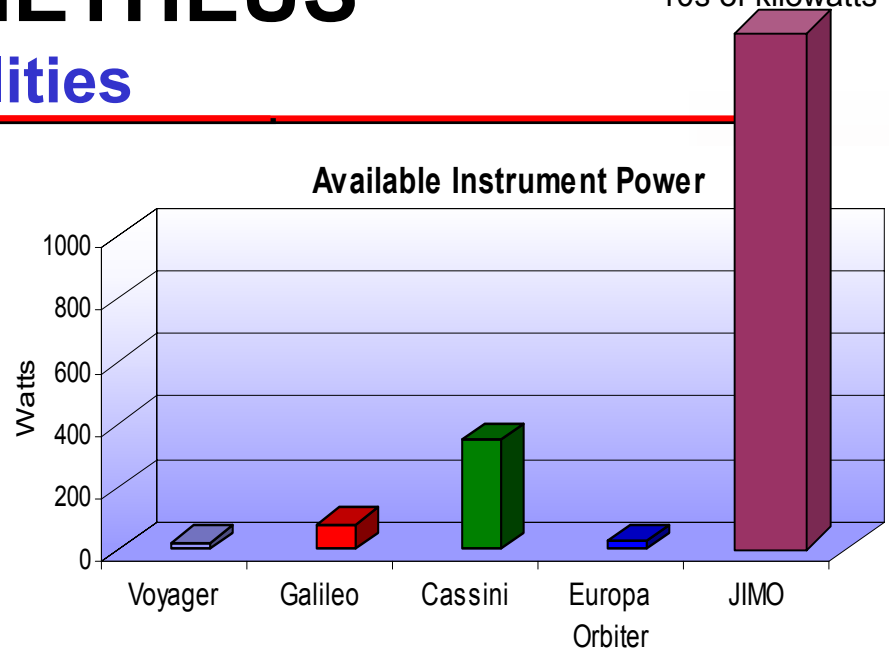
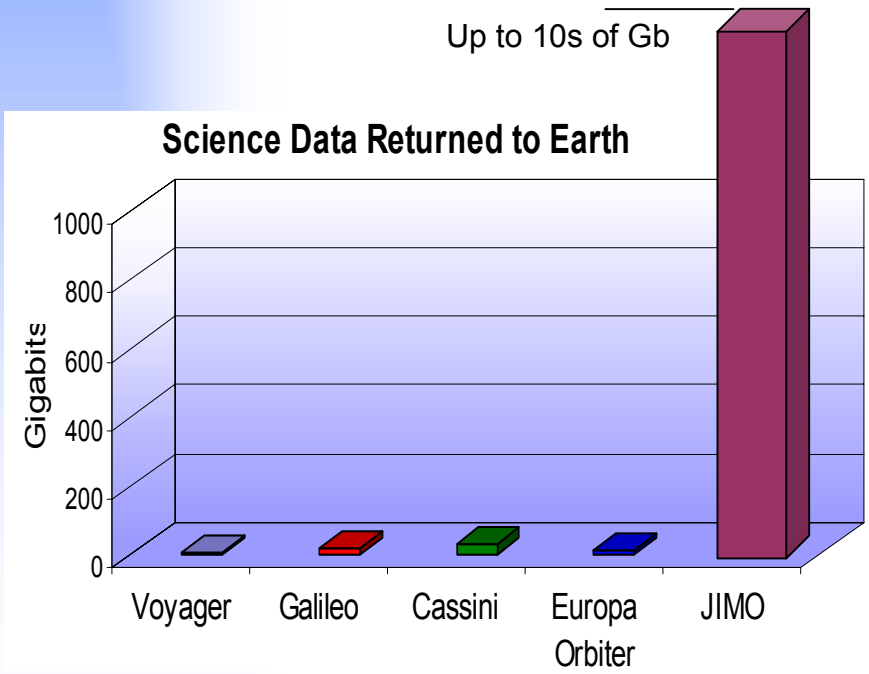
Revolutionary Capabilities

Amount of **POWER** available to science instruments

One bedside reading lamp compared to several homes



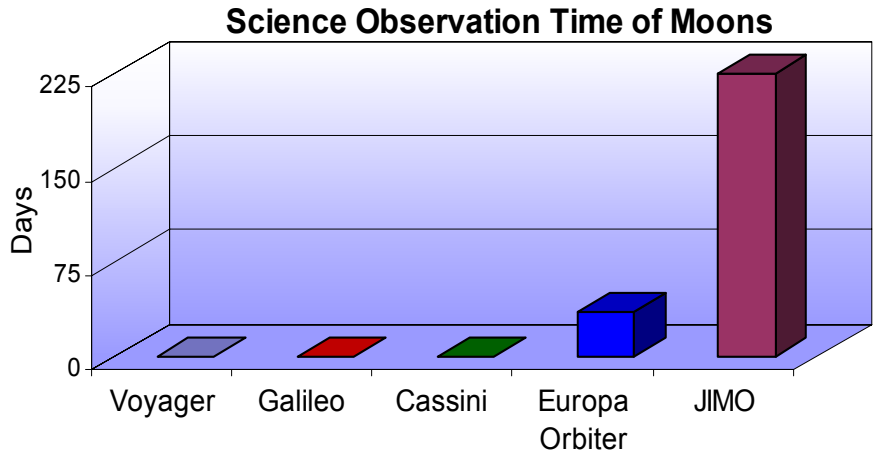


Amount of **SCIENCE DATA** return

1 – 2 floppy disks as compared to >20 CD-ROMs

TIME available for science observation of moons

1 to 5 hours compared to 180 days



Project Prometheus

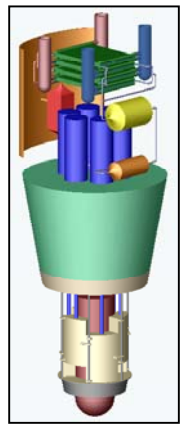
Nuclear Electric Propulsion

Nuclear Fission Reactor Research (DOE)

Objective: Research reactor power systems suitable for planetary science applications and support development of test facilities, autonomous systems, and reactor fuel.

– *Finished comprehensive reactor concept screening activity*

1) Heat pipe, 2) liquid metal, 3) gas



Liquid metal cooled reactor concept

Brayton power converter

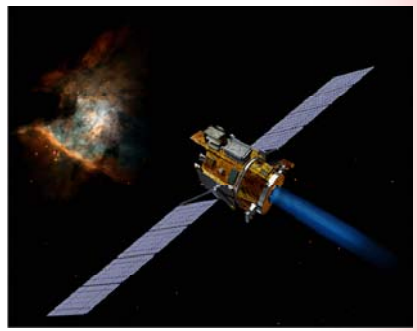
Power Conversion Research (NASA)

Objective: Research multiple high power thermal-to-electrical conversion technologies for nuclear electric propulsion (engineering unit - CY06)

-- Static (thermoelectric) and dynamic (Brayton &Rankine) conversion technologies

Electric Propulsion Research (NASA)

Objective: Research multiple high-power (20-50 kWe & up to 250 kWe) electric propulsion technologies for nuclear electric propulsion (engineering unit - CY06)



Deep Space 1 – ion propulsion

Project Prometheus

Jupiter Icy Moons Orbiter (JIMO)

- JIMO supports the recommendation from the National Research Council Decadal Survey for a Europa Geophysical Explorer mission as a high priority for a flagship mission in Solar System exploration.
- JIMO is a ***science-driven*** mission that would use new nuclear power technologies to enable science return far beyond previous outer planets missions
  - High power for instruments (including active) & high duty cycle
  - High data rates during acquisition and transmission
  - Large payload mass
  - Global orbital reconnaissance of all Jupiter's icy Galilean moons: Europa, Ganymede, and Callisto.
  - High delta-V capability enables multi-target rendezvous and close-range orbit and increased observation time at moons (Europa, Ganymede, and Callisto)

Artist's rendering of possible JIMO spacecraft

- JIMO would be the first flight mission to use nuclear power and propulsion technologies.
- This mission would set the stage for the next phase of exploring Jupiter and will open the rest of the outer Solar System to detailed exploration.

Project Prometheus

Conclusion

- **Project Prometheus would enable a new paradigm in the scientific exploration of the Solar System.**
- **We expect that the JIMO mission would be the first of a new generation of missions characterized by more maneuverability, flexibility, power, and lifetime and even greater scientific opportunity.**
- **Project Prometheus organization is established at NASA Headquarters and the Nuclear Systems Program is well under way:**
  - Organization established to carry out development of nuclear radioisotope power, nuclear electric power and propulsion, and JIMO
  - Assembled teams of dedicated scientists, engineers, and managers
  - Initiated JIMO trade studies
  - Awarded five NRA's for nuclear propulsion research & 10 NRA's for RPS power conversion
  - Negotiating nuclear reactor responsibilities with DOE
  - Coordination within NASA regarding future power needs (milliwatt to kilowatt)
  - Engaging scientific community in extensive discussions to define science objectives for JIMO and to identify future opportunities
  - Initiated risk communication and E/PO planning
- **We know this will be difficult technically and politically. Each person involved [and committed] will help us toward our goals.**
- **Challenges are many, time is short, but the rewards are great. We can make a great impact on our knowledge of the solar system.**

- *Werner von Braun: "We can lick gravity but sometimes the paperwork is overwhelming." (A.S. Levine, 1982, Managing NASA in the Apollo Era, NASA: Washington, DC)*
- *It is easy to go nowhere. . It requires no energy and has no risk except that of being left behind . To go forward and run ahead is a supreme test. – unknown*